Dynamics of mesoscopic magnetic systems

C. Quitmann
Swiss Light Source, Paul Scherrer Institut
Outline

• Introduction Swiss Light Source
• Scanning Transmission X-Ray Microscopy (STXM)
• Magnetization Dynamics
  – Mesoscopic magnetic objects & magnetization dynamics
  – Topology & static behavior
  – Modified coupling
  – Dynamics in trilayer squares
• Possible collaboration SOLARIS – PSI?
What is a synchrotron?

- Electro-magnetic radiation
  - $E \sim 1\text{meV} \sim 10^1 \text{keV}$
  - Polarization
  - Brightness
SLS machine – A few facts

- **E = 2.4 GeV**
- **Circumference = 288 m**
- **TBA lattice**
  - 12 * 3 dipoles (1.4 Tesla, $E_c = 5.5$ keV)
  - 12 straights (3×11.5 m, 3×7 m, 6×4 m)
  - 1 injection + 1.5 RF
- **3 “Super” bends: H = 3 Tesla (E< 35 keV)**
- **Emittance**
  - $H= 5.5$ nm rad
  - $V = 3$ pm rad
- **Fast feedback < 200Hz (73 steering magnets)**
  - Stability < $\sigma/10$
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X-Ray Microscopes

Fig. 1: Three different types of x-ray Microscopes
http://www-ssrl.slac.stanford.edu/dichroism/XDSM/Mic1_large.gif


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STXM Beamline & Endstation

bending magnet (X07DA, PolLux)
SLS storage ring
toroidal mirror
monochromator
zone plate
STXM
OSA
sample
APD detector
scanning stage controller

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Scanning Transmission X-Ray Microscope

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www.silson.com/
Scanning Transmission X-Ray Microscopy

Contrast:

\[ I_{\text{Trans}} = I_0 \exp[-\mu(Z, h\nu)t] \]

- Thickness
- Chemical
  - Element (Z)
  - Bonding
- Orientation
- Magnetic
- …
Magnetic absorption spectroscopy: XMCD

\[ \Delta E \sim 1 \text{eV} \]

\[ \Delta \ell = \pm 1 \]
\[ \Delta s = 0 \]

\[ I_{\pm,-}(E_{\text{Photon}}, \sigma) \sim \left| \left\langle f_{3d} | \vec{E}_x \cdot \vec{r} \pm i \vec{E}_y \cdot \vec{r} | i_{2p} \right\rangle \right|^2 \rho_f(E_{\text{Fermi}}, \sigma) \]

**Theory:** J.L.Erskine et E.A.Stern, Phys.Rev.B 12, 5016 (1975)


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Mesoscopic magnetism

- Vortex
- Domain wall
- Domain

J. Raabe, PRL 94, 217204 (2005)


Relevant time scales

$>10^6$ s  Long term stability

1 s  Thermal activation: domain nucleation & growth, viscous regime

1 ms

1 $\mu$s  Precession ($\gamma = 17.6$ Mhz/Oe): precessional switching

1 ns  Ultra-fast demagnetization: Spin-spin & spin-lattice interaction

1 ps

1 fs  Atomic physics

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Magnetic length scales

- 10^4 km
- 1 cm
- 100 µm
- 10 µm
- 1 µm
- 100 nm
- 10 nm
- 1 nm
- 0.1 nm

- Engineering
- Astrophysics
- Mesoscopic objects
- Hard disk
- Domain wall
- Exchange length $\xi$

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Simulating domain patterns ;-)
\[
\frac{d}{dt} \vec{M} = -\gamma_0 \vec{M} \times \vec{H}_{\text{eff}} + \frac{\alpha}{M} \left( \vec{M} \times \frac{d}{dt} \vec{M} \right)
\]

Precession
\[\omega_0 = \gamma \cdot H_{\text{eff}} = \gamma \cdot \frac{\partial E_{\text{tot}}}{\partial \vec{M}}\]
\[\gamma = 17.6 \frac{\text{MHz}}{\text{Oe}}\]

Damping
\[\alpha \approx 0.01 - 1\]

Numerical simulations:
- LLG (M. Scheinfein)
- OOMMF (NIST)
- …


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Resonant Pump - Probe

Probe: 500MHz

Pump: 500MHz / n

n = 4: 125 MHz

Measure: $\Delta M_0(\nu)$, $\Delta \phi(\nu)$
STXM for magnetization dynamics

PSI, FZR-Dresden, MPI-Stuttgart

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Detector: single photon counting

- Single photon sensitivity: shot noise limited
- Rise time $\sim 10^2$ ps: pump-probe experiments

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Frequency dependance

- Square: Co, 2 x 2 µm, t= 50 nm
- Vary excitation frequency: 125 / 250 / 375 MHz
- frequency resolution: $\Delta f = 500 \text{ MHz} / n$
  
  $n = \text{number of counters (typ.: 4, 8)}$
Why magnetic bi-layers

• More complex
  – static
  – dynamics
• Tune coupling
  – Interlayer spacing (IEC – dipolar)
  – Ion beam irradiation
  – Demagnetization
• Goals
  – Understand dynamics
  – Controlled switching
    Config1 $\Rightarrow$ Config2 ??
# Bi-layer vortex topology

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>in-plane circulation</th>
<th>counterclockwise, clockwise (+1,-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>core polarity</td>
<td>up, down (+1,-1)</td>
<td></td>
</tr>
<tr>
<td>(H = C \cdot p)</td>
<td>vortex handedness</td>
<td>right handed, left handed (+1,-1)</td>
<td></td>
</tr>
</tbody>
</table>

### FM state

<table>
<thead>
<tr>
<th>Co</th>
<th>C</th>
<th>(H_{Co} = +1)</th>
<th>(H_{Co} = -1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>NiFe</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>p</td>
<td>(\pm 1)</td>
<td>(\pm 1)</td>
<td>(\pm 1)</td>
</tr>
</tbody>
</table>

\(H_{NiFe} = \pm 1\)

### AFM state

<table>
<thead>
<tr>
<th>Co</th>
<th>C</th>
<th>(H_{Co} = +1)</th>
<th>(H_{Co} = -1)</th>
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<td>+1</td>
</tr>
<tr>
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<td>(\pm 1)</td>
<td>(\pm 1)</td>
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\(H_{NiFe} = \pm 1\)

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The PolLux Beamline

An example of what is possible at SLS

Collaboration: PSI & Solaris?


U. Flechsig,
"The PolLux Microspectroscopy Beamline at the Swiss Light Source"

S. Henein
"Mechanical Design of a Spherical Grating Monochromator for the Microspectroscopy Beamline PolLux at the Swiss Light Source"

M. Böge
"Fast polarization switching at the SLS microspectroscopy beamline POLLUX"
FIG. 1. (Color online) Optical layout of the PolLux beamline (not to scale) showing the bending magnet source followed by the toroidal mirror and the spherical grating monochromator. These create a secondary source at the exit slit (S2) illuminating the FZP which produces the focal spot across which the sample is scanned. The photograph on the right shows several of the beamline components.
FIG. 2. Measured photoion yield at the nitrogen $1s \rightarrow \pi^*$ transition using the gas cell located between exit slit and FZP of the PolLux beamline (300 lines/mm grating, 10 μm slits). The intensity ratio of the first minimum to the third maximum (0.8) indicates an energy resolution in excess of $E/\Delta E \sim 5000$ (Ref. 23).

FIG. 3. (Color online) Resolving power (left scale) and relative intensity (right scale) as function of the entrance slit width measured with the 300 lines/mm grating at an exit slit of $50 \times 50$ μm$^2$. The resolving power has been determined from the N$_2$ spectra shown as insets. The lines indicate the resolving power for equal entrance and exit slits matched to the horizontal focus width at the entrance slit (FWHM=165 μm).

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E 3. Predicted relative transmittance in different diffraction orders and higher order content of the beamline (left) and 600/mm grating (right).
Circular polarization from BM

FIG. 6. Scheme showing how circularly polarized light is obtained from a bending magnet by tilting the storage ring orbit relative to the optical axis of the beamline. The beamline acceptance is $\psi_0$; the tilt angle of the orbit is $\Delta\psi$ ($\leq \pm 300 \ \mu\text{rad}$).

FIG. 9. (Color online) Magnetic imaging of a CoPt/InMn multilayer sample (total Co thickness=6 nm). The well known worm domains of about 200 nm width are shown in (a), a spectrum taken at the Co L edge in (b), and the magnetic contrast and relative intensity as a function of bump angle $\Delta\psi$ in (c).

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Polish Beamline @ SLS?
Status of discussion

- Beamline built & financed by SOLARIS
- Design & installation support by SLS
- Operation @ SLS ~3 years
- Endstations:
  - PEEM & XAS
- Transfer to Krakow once SOLARIS is operational

**Pro:**
- Learn how to build & operate BL
- Good value for money
- A Polish BL as soon as ~2012
- Science collaboration PL & CH

**Contra:**
- No undulator
- Complicated agreement EU – SOLARIS - PSI
The Future?

PSI + SOLARIS:

POLish Advanced Research Instrument in Switzerland

„POLARIS“
Thanks to the people!

J. Raabe, A. Puzic
U. Flechsig
T. Korhonen, B. Kalantari, U. Greuter
S. Wintz, T. Strache

PolLux
PSI
FZ-Dresden
Thanks for your attention!

SLS by night

http://www.psi.ch/sls/